Field performance availability improvements in lithography light sources using the iGLX™ Gas Management System

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ABSTRACT

At high-utilization lithography sites, laser light source gas replenishments and gas maintenance operations typically require between 9 and 16 hours per year, during which the light source is unavailable for pr oduction. Reducing this downtime is important for increasing the productivity of the lithography cell. Light sources also require intermittent gas maintenance that must be performed manually and therefore can be subject to variability in duration and rep eatability.

This paper will outline the targeted improvements in availability achieved by equipping the light source with Cymer's iGLX™ Gas Management System. The iGLX System extends the pulse-based interval between gas refills to 4 billion pulses for Cymer's XLA-series and XLR-series light sources, while maintaining existing performance. Additionally, the iGLX System automates some gas maintenance events that were previously manual, improving their speed and reducing variability. This paper will provide some performance data during extended light source operation on lithography cells equipped with the iGLX System.

For high-utilization lithography cells, the iGLX System can reduce gas maintenance related downtime by up to 75%, increasing light source availability up to 12 hours per year. Total halogen gas usage can also be reduced by up to 16%, and manual gas maintenance events can be eliminated.

The iGLX System has been installed on multiple high-volume scanner systems, which experienced these improvements immediately, and are continuing to operate nominally. As the iGLX System is deployed in volume, additional availability improvements can be realized by more readily synchronizing other lithography line maintenance events with gas replenishment events.

Keywords: light source, uptime, availability, gas, gas control, iGLX, gas optimization, CoO

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1. INTRODUCTION

Lithography wafer throughput requirements are continually increasing to enable revenue growth for large volume chip sales. These higher throughput requirements directly require increased uptime and availability for all lithography cell subsystems. The light source is a key subsystem enabling most stages of the lithography process: an improvement in light source uptime will pass almost completely to the lithography cell. Therefore, increased light source availability is highly valuable, even in small increments.

The SEMI E10 Standard[1], depicted in Figure 1, defines scheduled downtime to include preventative maintenance and replacement of consumables, which would thereby include halogen gas fill replenishments and optimizations of the gas fill. This is time that the equipment cannot be used for wafer production. (The presumed industry ideal is to have the equipment total time equal to productive time.) Therefore, reducing time spent on gas replenishments and optimizations will reduce the scheduled downtime and increase productive time.

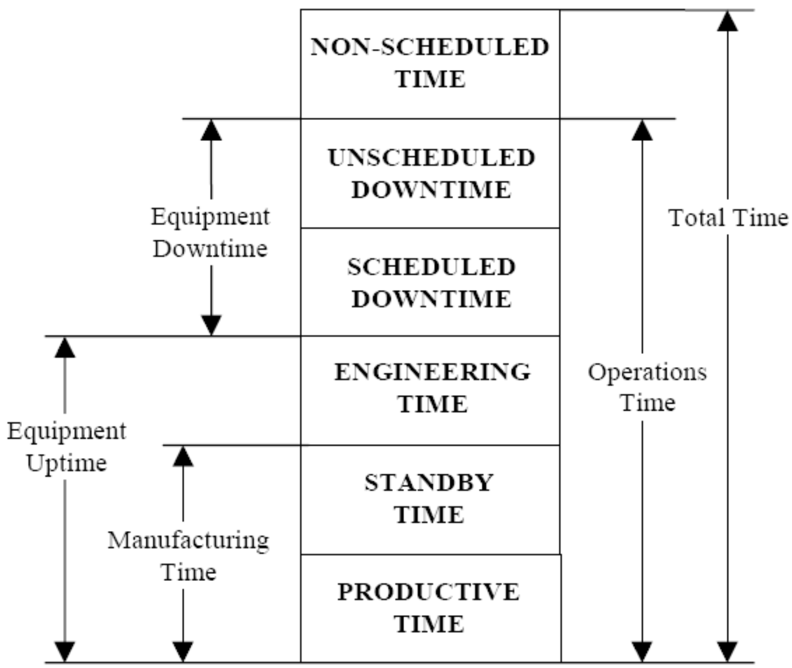

Figure 1. SEMI E10 Standard showing the breakdown of lithography equipment time.

Additionally, light source consumables contribute to the total cost of operation of a lithography cell. One such consumable is halogen gas, which must be constantly maintained through small replenishments (called “injects”) and periodically fully replaced (via “refills”). Reducing the gas usage rate will further increase chipmaker revenue.[4]

To achieve these dual goals of reduced gas maintenance time and reduced gas usage, Cymer developed the iGLX™ Gas Management System and deployed it to several light sources at customer sites. These customers immediately received – and continue to enjoy – the promised benefits, and the light sources continue to operate nominally. The iGLX System creates these improvements through a combination of software and algorithm upgrades, coupled with a deeper understanding of operational conditions and light source hardware operations and interactions.

[4] Gas usage reduction also has ecological benefits arising from the production and disposal or reclamation of the gas. Production of some of these gases is a product of fossil fuels, and both production and disposal or reclamation use considerable energy.

This paper will briefly describe the iGLX System, and present examples of field lasers running the iGLX System at chipmaker sites, showing the improved performance. In section 2 we will review the iGLX System concept. In section
3 we compute the improvement in uptime and predict it from the iGLX System's design. In section 4 we present and discuss data from lasers running the iGLX System, showing performance across the iGLX upgrade. Finally, in section 5 we provide conclusions and proffer further advances and technologies.

2. THE IGLX™ SYSTEM CONCEPT

Over many years of observing fielded light sources and understanding the critical aspects of gas control, Cymer has continually applied this learning to the development of new controllers. In the development of the iGLX concept, this led to three key concepts that built on Cymer's successful GLX™ Gas Management System[2] and are incorporated into the iGLX System:

1. **Decoupling of previously coupled control components**. The reduced complexity of a decoupled system provides for greater understanding of the controlled dynamics, and allows each decoupled component to achieve its maximum performance, rather than each component subject to the performance limitations of coupled components. iGLX achieved nearly complete decoupling of the master oscillator (MO) and power amplifier (PA) gas controllers, which improved gas control of each chamber individually. This led directly to the increased interval between full gas refills.

2. **The increasing importance of initial conditions**. It is known that the behavior (e.g. stability, convergence) of nonlinear systems, such as the iGLX Gas Management System, depends on initial conditions. Such dependencies increase with performance demands, so initial conditions must be better controlled to ensure the system behavior is as required.[3] The iGLX System contains two components for improving initial conditions:

    a. Improved accuracy of gas refills ensures that the gas state on a refill is very close to the target state, which limits variations and uncertainty in initial conditions.
    b. Ability to automatically set the gas to a repeatable and optimum state at any time, with minimal added downtime, which, coupled with the improved refill accuracy, allows accurate initial conditions to be achieved.[5]

3. **The increasing importance of some nonlinear effects to the control**. Again, as gas control performance demands increase, the effects of nonlinearities become more prevalent. The iGLX System incorporates several new signals and parameters into the controller that deal with nonlinearities. Some of these help improve the accuracy of gas actuations, others improve the accuracy of the initial conditions, mentioned above, and others help handle large-scale changes in operational conditions such as module aging and firing patterns.

Figure 2 shows the iGLX Gas Management System illustrating these concepts. Key differences from the GLX System concept[2] are:

- Partial separation (decoupling) of the MO and PA controllers, for the purpose stated above. The decoupling remains incomplete, since there are several common elements among the two that still benefit from some coupling.
- The inclusion of laser operational data, which is used for both state estimation and to directly affect the controllers to handle some influential nonlinear effects.
- The inclusion of laser configuration information to directly affect the controllers, which is used to handle some nonlinear effects and to more accurately achieve targeted initial conditions.

While the core gas control concept has remained intact, these changes introduce a new level of understanding to gas control and enable the increased performance and improved availability shown in the sequel, without compromising performance.

[5] Section 3 will discuss the automated gas optimization in the context of increased availability.

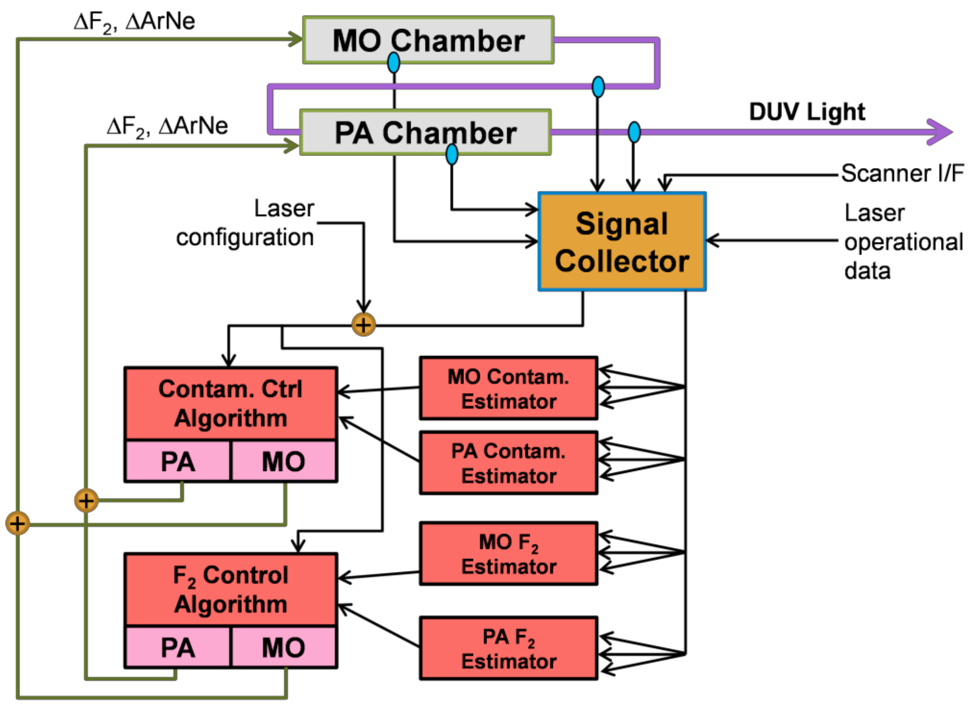

Figure 2. iGLX concept block diagram

Finally, Cymer's increased understanding of halogen gas dynamics has led to a method to reduce the usage of halogen gas while still achieving the performance improvements discussed above. This involved an optimization at the design phase. The cost function in the optimization includes gas usage as well as light source performance, and the trade-offs between these resulted in a small but critical shift in the computation of gas actuations under the iGLX System. This shift resulted in a net gas usage savings with the iGLX System, in addition to the savings resulting from fewer gas refills. Reference [4] provides a more detailed discussion and prediction of gas usage savings.

3. IGLX™ AVAILABILITY AND PREDICTABILITY IMPROVEMENTS

As gas control has improved, it has become a smaller and more predictable factor in light source availability.[4] The iGLX System extends the required interval between gas refills to 4 billion pulses. With increasing interval between full gas refills, the total time spent during this scheduled downtime has decreased.[4] Also, although gas refills are not required to follow the predicted schedule[6], the resultant variation is typically an absolute value, and not related to the total time between refills. Therefore, the relative contribution of this variation has decreased rapidly under Cymer's earlier GLX™ System, and further with the iGLX System, thereby improving the predictability of these gas functions.

Another gas-related function resulting in scheduled downtime is gas optimization events. These are used to adjust the target gas state to account for variations in laser performance, particularly as modules age, enabling the light source to continue to operate at peak performance and avoid unscheduled downtime. With previous gas control systems (e.g. GLX), these have been manual events that require service personnel and typically take approximately one hour to execute. To minimize these events, they are performed only when needed, which can often depend on specifics of light source operation, usage patterns, and variations in the ages of the installed modules. Therefore, the predictability of these gas optimization events has been poor.

[6] In fact, additional refills are often driven by unrelated scanner operations.

The iGLX System introduced automated gas optimization. It requires no more than 5 minutes and is performed automatically in conjunction with the gas refill. Not only does this minimize the downtime for gas optimizations, it eliminates their unpredictability. It also ensures an optimal post-refill light source gas state for the subsequent gas life, minimizing gas related performance variability.

Figure 3 depicts idealized downtime associated with gas functions for GLX, GLX2, and iGLX (small steps are due to refills, large steps are due to manual gas optimizations). Although the iGLX gas refills require approximately 20% more time than GLX and GLX2, they are 50% less frequent, enabling the downtime improvement shown. Note that iGLX does not require manual gas optimizations. Current high-volume memory fabricators often accumulate 40 billion pulses in a year on a light source. Therefore, Figure 3 implies the iGLX system can save between 6 and 12 hours of scheduled gas-related downtime per year, or up to 75%.

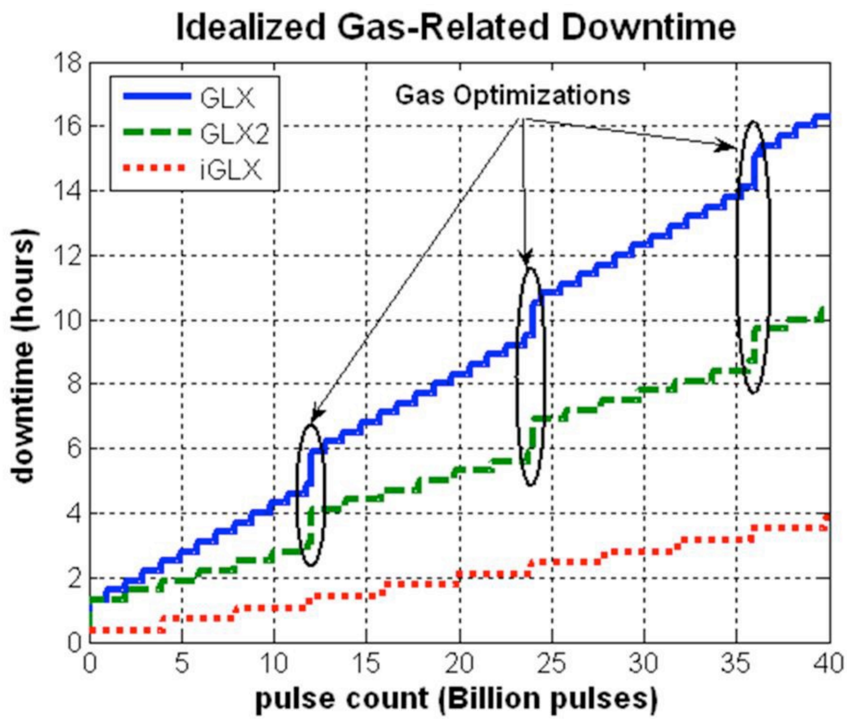

Figure 3. Gas-related downtime estimates

In more real-world circumstances, gas refills are often performed early, for example to synchronize with some other service events in the lithography cell This early refilling will tend to increase the downtime for GLX and GLX2 more than for iGLX, where early refills introduce a smaller relative variation. Additionally, real-world situations may require manual gas optimizations more frequently than depicted in Figure 3 (for example, because of asynchronous module replacements dictated by chipmaker scheduling, each of which may require a new gas optimization). This will further increase the benefit of iGLX, since the automated gas optimization schedule is not subject to the variations in chipmaker schedules or module combinations.

As iGLX is deployed and operated in volume throughout the world, actual performance versus these predictions will be revealed. The benefits are exhibited most clearly over a year of operation under typical fab conditions. As throughput and pulse rates continue to increase, the trend in Figure 3 shows the chipmaker benefits will increase accordingly. The next section will provide some performance demonstrations of these benefits on a few deployed systems.

4. IGLX FIELD PERFORMANCE DATA

The iGLX™ Gas Management System has been deployed to several high-volume memory chipmakers around the world. Performance data from three of Cymer's XL series light sources have been collected and are shown in Figure 4 through Figure 6. These figures show the key performance metrics of voltage and bandwidth, as well as the gas refill events.
The voltage is a measure of the light source efficiency and performance stability, and the bandwidth is one indicator of the long-term gas state stability. For comparison, data from before and after the iGLX installation are shown.

Figure 4 shows an iGLX installation on a Cymer XLA-400 series light source that occurred during a major service event where several aged modules were replaced. This explains the step changes in the performance signals at the start of
iGLX operation. Note the longer interval between refills for iGLX. The long-term rise in voltage is due to module aging, and is expected for a nominal light source with GLX2 and iGLX operation. However, iGLX operation tends to provide a smoother rise in voltage even across the refills, while GLX2 operation tends to induce some small transients across
refills. While this does not impact on-wafer performance, the iGLX behavior aids in predictability and reduces variability arising from inconsistent module ages, which can improve monitoring and help with synchronized maintenance
activities, thereby reducing service costs.

Additionally, the bandwidth signal is stable over the long term. The light source in Figure 4 does not have active bandwidth stabilization, so the long-term bandwidth stability is due very directly to gas state stability, and shows the efficacy of the iGLX System.

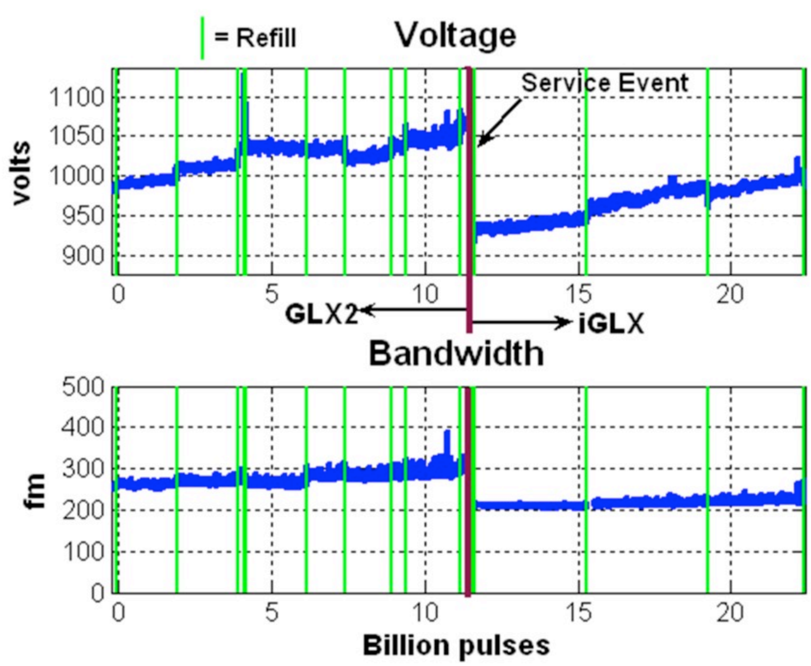

Figure 4. iGLX performance data from first field installation

Figure 5 shows an iGLX installation on another Cymer XLA-400 series light source that occurred in between major service. This provides a more direct comparison between GLX and iGLX performance. Except for the longer interval between gas refills, there are no significant differences in long-term performance between the two gas controllers. Voltage and bandwidth performance remain comparable. The faster rise in voltage later in the data is typically an indication that some modules may be approaching their end of life. With iGLX, such trends are more easily measured, which helps service personnel accurately select the correct maintenance activities.

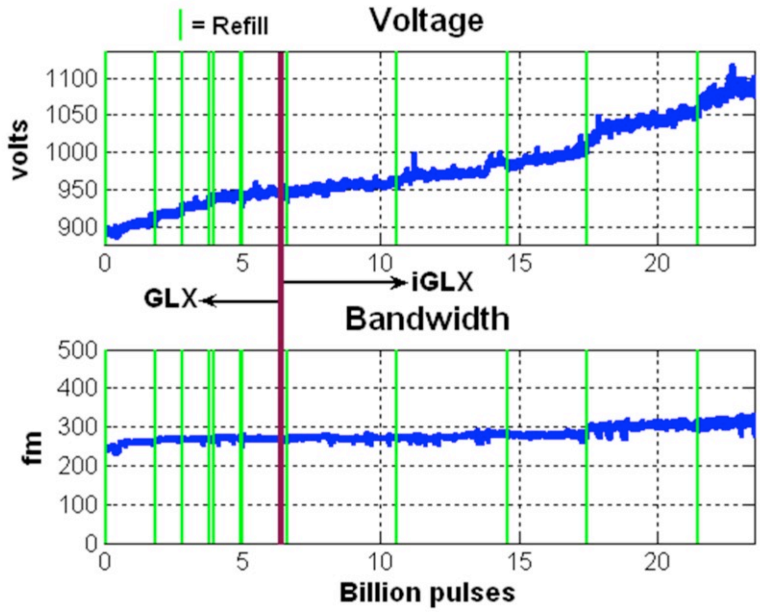

Figure 5. iGLX performance data from second field installation

Figure 6 shows an iGLX installation on a Cymer XLR-600 series light source where some of the key modules were approaching end of life, and were then replaced at around the 13.5 billion pulse mark. Additionally, note the refill events around 11 billion and 15.5 billion pulses. There is a large change in voltage across these refills. These are the result of
the automated gas optimization feature working to maintain light source performance in the face of strong transient conditions at the end and beginning of key light source module lives.

Before the module replacements, the modules were approaching their end of life, which can be a stressful period for maintaining performance, since the end-of-life behavior can be very different from nominal. The automated gas optimization here needed to use all of its available adjustment range to maintain total laser performance. This resulted in an increase in voltage at the refill, so that other critical parameters could be maintained in a good performance range.
The iGLX System and automated gas optimization adjust to these conditions without user intervention on each gas refill.

After the module replacements, the modules are in another off-nominal period as early life transients converge to normal operation. The iGLX system and automated gas optimization automatically adjust to this condition, as well. In this case, the adjustments can result in similar voltage transients across refills. After the early life transients converge, the iGLX system and automated gas optimization readjust to the new light source dynamics and continue to maintain long-term performance, including the extended interval between refills.[7] Note that such transients are a normal part of a light source's routine, and would occur equally with manual gas optimizations.

[7] Figure 6 shows some refill intervals with iGLX less than 4 Bp. These were due to unrelated and unplanned lithography cell maintenance events that disrupted laser gas state, which necessitated early refills before continuing.

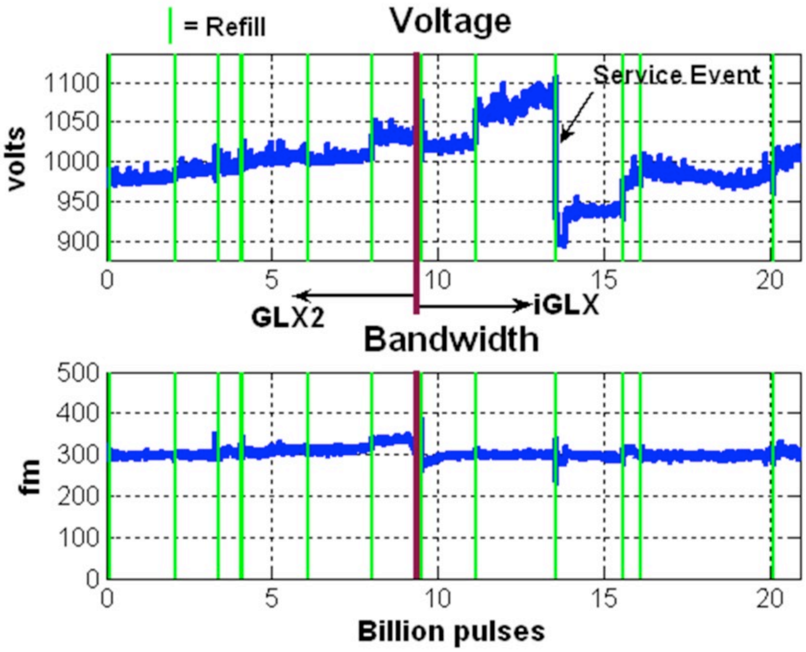

Figure 6. iGLX performance data from third field installation

Finally, Table 1 shows the actual savings of halogen gas usage with the iGLX system compared to GLX or GLX2. The savings depends heavily on the lithography cell's specific usage pattern. For example, periods of idle time still require some small gas usage to maintain the gas state against passive drifting. This will therefore use some halogen gas while no pulses are being accumulated. For this reason, light sources that have very high utilization tend to experience the most gas savings. Table 1 shows iGLX achieves significant savings of halogen gas usage in all cases, even under scenarios that are not ideal, as may be encountered in fielded systems at chipmakers.

savings First installation	
	15.7%
Second installation	12.6%
Third installation	10.6%

Table 1. iGLX halogen gas usage savings compared to GLX or GLX2

5. CONCLUSIONS AND FURTHER WORK

The control of the light source gas state is only a means to achieve performance of the light delivered to the lithography tool, and not in itself a fundamental performance metric. Therefore, gas control technology focuses mostly on reliability, uptime, and cost of operation, to support the overall lithography cell requirements. The evolution of Cymer's gas control technology in the past few years has demonstrated an order of magnitude decrease in gas-related downtime, while also improving light source stability, predictability and serviceability. Cymer's new iGLX™ Gas Management System continues this evolution, nearly doubling the uptime related to gas functions, increasing the light source predictability, reducing service costs through automated gas optimization, and reducing cost of consumables through gas usage reduction. These improvements have been demonstrated at several chipmakers as shown in this article, providing up to 75% reduction in gas-related downtime and up to 16% savings in halogen gas usage.

Given the pace of the lithography industry, requirements for continual and rapid improvements are expected. Anticipating this, Cymer is looking for opportunity to further enhance light source gas control technology. Some extant options include extending refill intervals to match (or exceed) the life of the laser chambers, effectively eliminating the refill operation altogether[8]; removal of the discrete gas optimization, which will avoid *all* gas related downtime; further optimizing the usage of gas, tailored for each of the wide range of usage patterns exemplified by the different chip- making sectors (i.e. memory, foundry, and logic); and using gas control not just as a stabilizing system, but as an active element in the control and adjustment of key laser performance metrics.

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[8] There is a diminishing return of such an "infinite" extension to the refill interval, since other scanner operations often require downtime that would allow for synchronized refill operations, and therefore increased refill intervals would not increase overall lithography cell uptime.